A Load-Balancing and Push-out Scheme for Supporting QoS in MANETs

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Abstract. Currently, mobile ad hoc networks (MANETs) lack load-balancing capabilities, and thus, they fail to provide good performance especially in the case of a large volume of traffic. Ad hoc networks lack also service differentiation. However, in these wireless environments, where channel conditions are variable and bandwidth is scarce, the differentiated services developed for the Internet are suboptimal without lower layers' support. The IEEE 802.11 standard for Wireless LANs is the most widely used WLAN standard today. It has a mode of operation that can be used to provide service differentiation, but it has been shown to perform badly.
In this paper, we present a simple but very effective method for support Quality of Service, by the use of load-balancing and push-out scheme. This approach offers to the mobile node: the ability to alleviate congestion by traffic distribution of excessive load, and to support priority of packets in the single MAC buffer. We evaluate the performance of our algorithm and compare it with the original IEEE 802.11b protocol. Simulation results show that this new approach reduces packet loss rate and increases throughput as well as provides service differentiation in the MAC layer.

Keywords: MANETs, QoS, load-balancing, push-out, Mac Layer.

1. Introduction

A Mobile Ad hoc Network (MANET) [Perkins. (2001)][Chlamtac, Conti and Liu. (2003)] can be defined as an autonomous distributed system that consists of a set of identical mobile nodes that move independently and freely. Each node communicates over relatively bandwidth-constrained wireless links with other nodes that reside within its transmission range. And because of limited radio propagation range, mostly routes are multi-hop.

Ad hoc networks are useful in many applications because they do not need any infrastructure support. Sensor networks, disaster recovery, rescue and automated battlefields are examples of application environments. Without no base station or centralized administration, the nodes are free to move randomly and organize themselves arbitrarily. Thus, the networks topology may change rapidly and unpredictably.

Actually, with the evolution of Multimedia Technology, Quality of Service (QoS) in MANETs becomes an area of great interest. And beside the problems that exist for QoS in wire-based networks, ad hoc networks impose various new constraints:

Dynamic topology:

Which evolves very quickly because each node can move arbitrarily and disappear randomly without any notification, from where need for routing mechanisms, which adapts with the nodes connectivity at a given moment.

Radio channel of communication:

Indeed the connections are with variable rates and limited bandwidth.

Power consumption:
The autonomy of a mobile node is limited in term of energy. Moreover, each node serves as a host as well as a router and uses consequently its own energy to route flows intended for other nodes of the network.

Limited security:
Since ad hoc networks are more vulnerable to physical security threats, provisions for security must be made.

The ability to provide an adaptive Quality of Service (QoS) in a mobile environment is a key to the success of next generation wireless communications systems. Quality of service can be defined as a set of service requirements that needs to be met by the network while transporting a packet stream from a source to its destination. The network needs are governed by the service requirements of end user applications. The network is expected to guarantee a set of measurable prespecified service attributes to the users in terms of end-to-end performance, such as bandwidth, delay, packet loss and jitter. Another QoS attribute is the power consumption, which is more specific to MANETs.
Recently there has been a considerable amount of QoS research. However, the main part of this research has been in the context of framework components, and much less progress has been made in addressing the issue of a group management to provide QoS within an ad hoc network. The buffer management is usually one of the most essential and challenging in such a dynamic environment. Therefore, there is a need for load-balancing to allow all nodes the opportunity to enhance their use of network resources.

In this paper, a novel load-balancing and push-out scheme for Mobile Ad hoc Networks is presented. Currently, MANETs lack load-balancing capabilities, and thus, they often fail to provide good performance and a certain Quality of Service, especially in the presence of a large amount of traffic. We present a simple but an effective technique to achieve load-balancing when congestion appears in an ad hoc network. The new scheme is motivated by the observation that the original MAC 802.11 layer does not provide any mechanism to handle node congestion.

In addition, we propose a push-out based queue management scheme with load-balancing algorithm that allows nodes to:

- distribute and efficiently use network resources (buffer space)
- reduce network congestion by change route
- increase overall performance (throughput)
- provide service differentiation to satisfy required QoS.

The enhanced version of MAC 802.11b protocol with this scheme is compared to the base protocol. Simulation results reveal that the new scheme greatly reduces packet loss as well as traffic load increases in the network, and it successfully balances the network load among nodes.

The contributions of this paper are as follows; we first briefly provide an overview of quality of service, and present related works and then describe our new approach in Section 4. In section 5, we evaluate performance of proposed algorithm through simulation experiments and compare it to the original MAC IEEE 802.11b [Marja-Leena. (2000)] [IEEE Std 802.11e/D8.0 (2004)]. Finally, we describe future work, before we conclude.

2. Quality of Service

Usually, we can define Quality of Service (QoS) as a set of service requirements that a network needs to meet while transmitting data from a source to a destination. The network needs are governed by the service requirements of end user applications. The network is expected to guarantee a set of measurable prespecified service attributes to the users in terms of end-to-end performance, such as delay, bandwidth, packet loss and jitter.

The growth of the number of hosts in the Internet leads both researchers and industrials to resolve the problem of how to support QoS, or how to support service differentiation in such environments. Recently, several working groups like IntServ or DiffServ try to deal with this problem for IP layer in wired networks. Furthermore, wireless networks show a more critical medium which also needs QoS support for multimedia and real-time applications, to deal with the increasing number of terminals and standards and with the nature of the wireless channel. Due to the dynamic nature of the network, it is not possible to apply QoS Management techniques to negotiate Quality between users and networks [Barry and McGrath (2003)].

In the literature, this QoS support can be done over all the layers in the network:

- **QoS models** that specify an architecture in which some kinds of services could be provided. It is the system goal that has to be implemented.
- **QoS adaptation**, which can hide all environment-related features from awareness of the multimedia-application above and provides an interface for applications to interact with QoS control.
- **QoS signalling** acts above the network layer, as a control centre in QoS support. The QoS model determines the functionality of QoS signalling.
- **QoS routing** that represent a part of the network layer and searches for a path with enough resources but does not reserve resources.
- **QoS MAC protocols** which are essential components in QoS ad hoc networks. QoS supporting components at upper layers, such as QoS signalling or QoS routing assume the existence of a MAC protocol, which solves the problems of medium contention, supports reliable communication, and provides resource reservation.

3. Related Works

Due to nodes mobility, the topology of an ad hoc network may change rapidly and unpredictably over time. The design of network protocols for MANETs is a complex issue; these networks need efficient distributed algorithms to determine network organization (connectivity), link scheduling and routing.
Actually, most routing protocols for MANETs, such as: Ad Hoc On Demand Distance Vector Protocol (AODV) [Royer and Perkins. (2000)], Temporally-Ordered Routing Algorithm (TORA) Protocol [Park and Corson. (2004)], Dynamic Destination-Sequenced Distance-Vector Routing protocol (DSDV) [Perkins and Bhagwat. (2004)], are designed without explicitly considering quality of service of the routes they generate. These routing protocols provide the capability for establishing minimum-hop paths between nodes on a best effort basis [Royer and Perkins. (2000)] [Perkins. (2001)] regardless of node status such as available buffer space. However, some applications, such as multimedia and real-time, need not only the capability to establish communications between nodes but also require of some Quality of Service guarantees on bandwidth, delay and bit error rate. Much research has been performed to provide levels of Quality of Service in wireless communication. A large amount of work on service differentiation has been carried out, especially via distributed mechanisms, as it is the case in [Aad and Castelluccia. (2001)], [Barry, Campbell and Veres. (2001)] and [Bianchi and Tinnirello. (2003)]. In [Nandagopal et al. (1999)], authors present the service differentiation of multiple classes of flows by reconfiguring the data sending rates in case of congestion. The flows with lower weight throttle their sending rate drastically, whereas the higher weight flows reduce their rate by small amounts.

A first attempt to analytically model these mechanisms appears in [Aad and Castelluccia. (2001)]: the proposed model is very simple though the memoryless assumption does allow to account for exponential backoff details. In [Barry, Campbell and Veres. (2001)]

authors discuss the problem of supporting distributed admission control rule on top of an enhanced version of DCF (Distributed Coordination Function), via the definition of virtual MAC algorithm, that passively monitors the radio channel and estimates the service levels available, plus a virtual source algorithm. In addition, service differentiation can be provided in contention-based MANETs, by controlling the behaviour of the backoff algorithm. Every flow can belong to one class. In this case, the sender of a flow marks all outgoing packets with its class in the DS field of the IP header. Before forwarding packets, the node checks the wireless medium. If the medium is free, the node forwards the packet to its neighbour.

In the case where the medium is used, the node tries to backoff their counters and waits a random amount of time before the next transmission. To perform a backoff action, each node looks up the incoming packets with applying different backoff algorithms depending on the packet's classes. This mechanism allows for some classes of flows to receive up to their requested target bandwidth [Kang and Mutka. (2001)].

All these works handle the problem of how to differentiate services by differentiating priority of the access to the wireless channel. In our approach, instead of access priority differentiation, we provide a service differentiation mechanism to handle packets over a class queuing system in the MAC layer. Also we present new packet discarding policy for router function of a mobile node to enhance end-to-end performance.

3.1. Load-balancing Algorithm

In general, the problem of congestion can occur in a network when offered traffic load exceeds available capacity at any point in the network. In ad hoc networks, congestion causes overall channel quality to degrade and loss rates to be increased.

It also leads to packet drops and increased delays, and tends to be grossly unfair toward nodes whose data has to traverse a larger number of radio hops. The goal of our previous work [Brahma et al. (2005)] was to propose an efficient load-balancing scheme in the MAC IEEE 802.11 layer to reduce the network congestion by changing the route when a node is congested and to distribute and efficiently use network resources, especially the buffer space.

The purpose of load-balancing is to:

- distribute excessive load of a node to its neighbors,
- increase and enhance network resource utilization (buffer, radio channel),
- reduce collision by load distribution,
- reduce the number of packets lost by buffer overflow and
- improve overall performance in MANET.

3.1.1. New Messages for load-balancing algorithm

For providing load-balancing ability in IEEE 802.11 MAC, we have designed new messages: HELP, OK and NOTIFY [Brahma et al. (2005)]. HELP message is used to ask help by broadcasting. OK message is used for response to a HELP request and NOTIFY message is for establish new route to the intermediate node as depicted in figure 1.

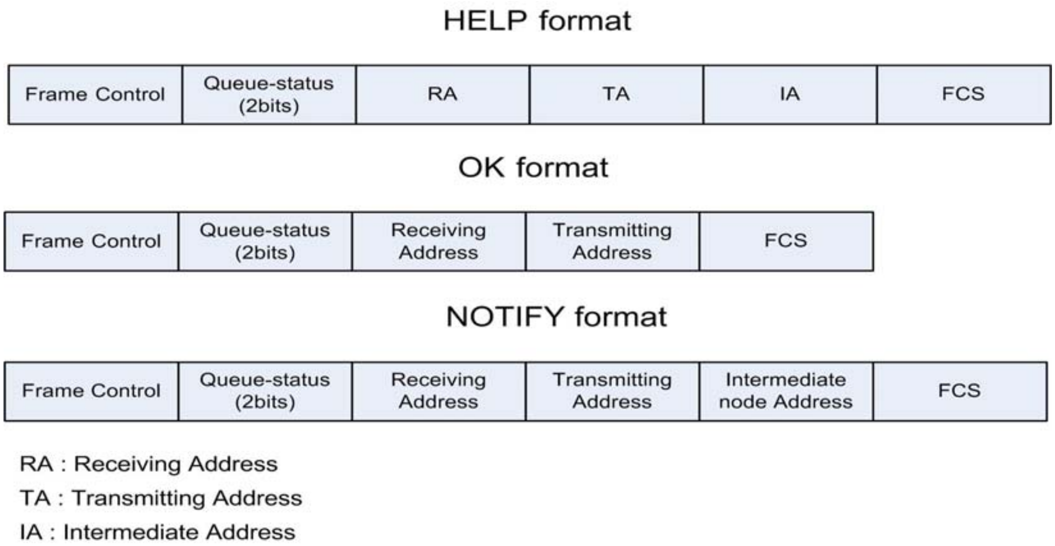

Figure 1. Packets' format

The size of queue-status field is 2 bit and each value means that; 0 is empty, 1 is low, 2 is medium and 3 is high. IA field is the address of an intermediate node.

Determine queue status

In load-balancing algorithm, we determine "queue-status" with queue occupancy for decision of congestion:

```
If queue_occupancy < low_threshold then queue-status = 0;
Else if low_threshold < queue_occupancy < medium_threshold
          queue-status = 1;
  Else if medium_threshold < queue_occupancy < high_threshold
              queue-status = 2;
       Else queue-status = 3;
```

Where queue occupancy is the ratio of the number of waiting packets at the queue over total queue space.

Decision to send HELP message

If 'queue-status' is greater than 2 when a node receives DATA packet, a node become congested node and sets IA to transmitting address of DATA packet and then broadcasts a HELP message to ask neighbors for help.

Decision to send OK message

When a node receives HELP message, if the 'queue-status' is less than the 'queue-status' of HELP packet and IA of HELP message is belong to my neighbors then a node sends OK packet to the congested node.

Send NOTIFY packet to the intermediate node

When congested node receives OK message, congested node sets IA of NOTIFY message to transmitting address of OK message and sends NOTIFY message to the intermediate node.

Receive NOTIFY and reroute DATA packet

When a node receives NOTIFY message, a node records NOTIFY to the database. After node receive new DATA packet, if RA of DATA packet is the same as RA in the database, a node replaces RA of DATA packet to IA that coupled with RA in the database.

3.1.2. Procedure of Load-balancing algorithm

When excessive traffic is offered to a node, the buffer of this node become full and it causes congestion. In this case lot of packets will be dropped. Load-balancing algorithm tries to release congestion status by distributing load of congested node to its neighbors.

Definition: *Congested node is which the queue occupancy is more than a certain level. For example: if the queue occupancy is more than 80% of total queue size,* **a node is considered as congested**.

Brief explanation of the load-balancing algorithm is as follows:

1) When a node receives ***DATA*** packet, if this node is congested, it broadcasts a ***HELP*** message to its neighbors with sender address 'B' as shown in figure 2 (a)

2) When a neighbor node receives a ***HELP*** message, if it has available buffer space and sender address 'B' is belong to its neighbors, this node send an ***OK*** packet to the congested node as shown in figure 2 (b)

3) The congested node choose the best node 'D' (which has the smallest queue status value) and send a ***NOTIFY*** message with address 'D' to the sender 'B' (figure 2 (c))

4) After receiving a ***NOTIFY*** message, the node 'B' change the route to the node 'D' from the congested node as same as figure 2 (d).

Remark: if all neighbor nodes are congested, they can not send ***OK*** and node B can not change route.

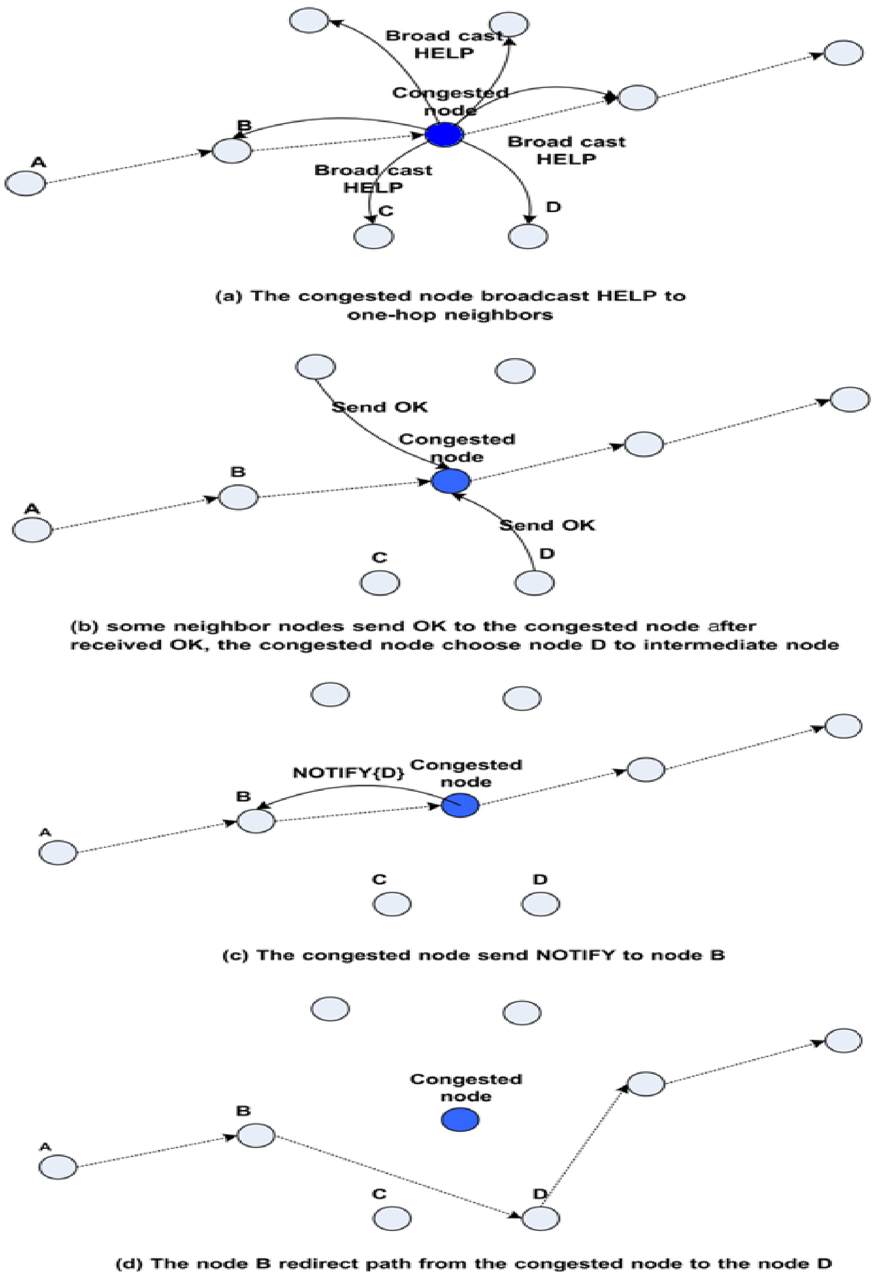

Figure 2. Load-balancing scenario

4. Queue management for QoS provision in IEEE 802.11b MAC

In pure IEEE 802.11b MAC protocol, single queue is used in best-effort manner and it has no capability to support quality of service guarantees such as bandwidth, delay and loss rate. In the proposed scheme, Packet Discarding Mechanism (PDM) can be used to manage the buffers in the mobile node. Under these mechanisms, the information carried by high priority packet is considered to be more important than information carried by low priority packet. In order to achieve certain level of loss performance, PDM with the priority queue can be used to reduce the loss rate of high priority packets at the expense of higher loss rate of low priority packets.

In this paper, we propose a push-out scheme to provide service differentiation for multiple classes in a single queue at layer 2. Push-out scheme has been used to provide service for multiple classes of traffic through one output buffer in a switch/router [Barry and McGrath. (2003)]. In the push-out scheme, when the buffer is full, the Packet Discarding Mechanism tries to drop some of previously accepted packets (low priority packets) to make available space for high priority packets. To simplify the mechanism, we define two classes of traffic; low priority for best-effort traffic and high priority for multimedia traffic.

The proposed buffer management algorithm is described as below. Where **QL** is the current queue occupancy, **HIGH_TH** is high threshold and **LOW_TH** is low threshold. These thresholds are used to control the buffer occupancy. The **IF_queue** is the interface queue between Link Layer and MAC Layer.

When QL exceeds LOW_TH and high priority packet arrives, the load-balancing mechanism is performed. But when QL exceeds HIGH_TH, if a low priority packet arrives to the queue, then the packet is dropped. Else, if a high priority packet arrives, Packet Discarding Mechanism tries to search low priority packets in IF_queue and discard them until QL becomes lower than HIGH_TH. The proposed algorithm offers to mobile nodes in an ad hoc network the ability of avoiding congestion by distributing excessive load and supporting multiple classes in a single queue without scheduler. This covers the drawback of the complexity in push-out scheme. Figure 3 above illustrates the behavior of the proposed load-balancing and push-out scheme.

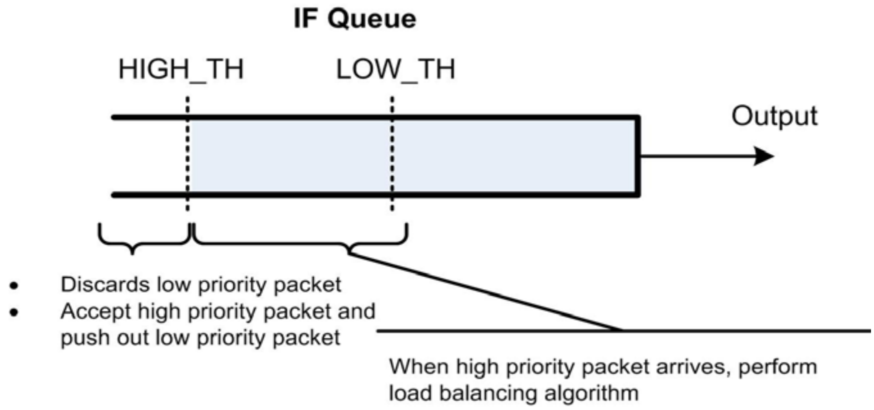

Figure 3. Proposed push-out mechanism

Detailed behavior of the proposed mechanism is shown as below:

On a packet arrival in the IF_queue

```
If (packet is low_priority) {
    If (QL > HIGH_TH) discards packet;
    Else accepts packet;
}
Else If (packet is high_priority) {
    If (QL => HIGH_TH) {
      While !(QL < HIGH_TH or no
      low_priority packet in IF_queue){
         Search a low_priority packet
         in the IF_queue and discard it
       }
```

```
    }
    Else If (QL > LOW_TH && QL <
            HIGH_TH){
     Performs load-balancing algorithm;
    }
}
```

5. Performance evaluation

We performed simulation to evaluate the validity of the proposed scheme and compared its performances with pure IEEE 802.11b MAC. We chose to study wireless simulation in the NS2 Network Simulator, which is a freely available discrete-event object-oriented network simulator. NS2 provides a framework for building a network model, specifying data input, analyzing data output and presenting results. Two network models are used for simulation. In the first one, 20 mobile nodes are generated to create an ad hoc network as shown in figure 4. The second network model consists of 50 mobile nodes and their positions are generated in random manner.

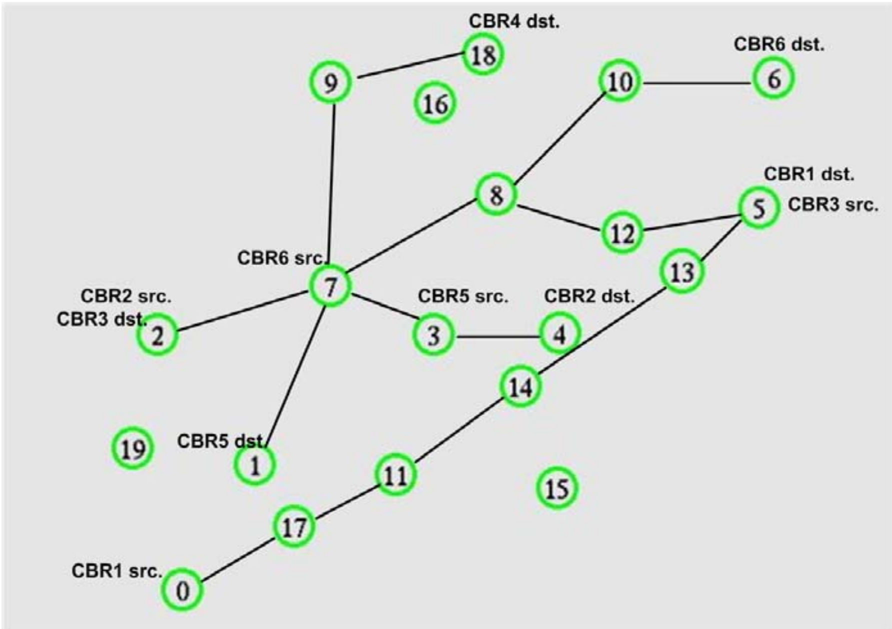

Figure 4. The first network model (20 nodes) for simulation

In all simulation, we used CBR (Constant Bit Rate) traffic source. Each CBR source generates packets every 0.05 seconds and the packet size is set to 1K bytes. Half of traffic sources are high priority class and rest of them are low priority class. For each model, we run simulation 10 times to avoid the bias of random number generation. The simulation time of the first network model (20 nodes) is set to 70 seconds, and 100 seconds for the second network model (50 nodes). In the first ad hoc network, the priority of CBR flows 1, 3 and 4 are set to high and flows 2, 5 and 6 are set to low.

5.1. Numerical Results of Fixed Topology

For performance evaluation of the push-out and load-balancing scheme, we executed simulations while varying the queue size from 10 to 50 packets.

Figure 5 plots an average number of received packets. It can be observed that the number of successfully received packets at CBR receiver of proposed scheme is slight better than that of original IEEE 802.11 MAC protocol.

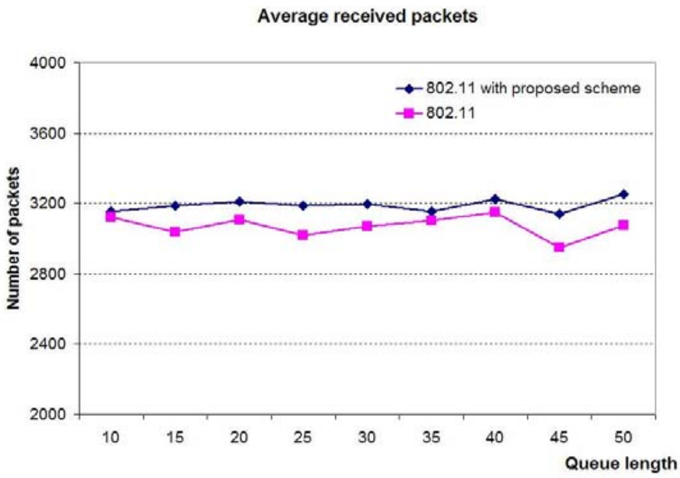

Figure 5. Average number of received packets

Figure 6 shows that the number of received high priority packets of proposed scheme is increased by an average of 25% than that of original IEEE 802.11 MAC protocol. The reason is that the proposed scheme increases throughput of high priority packets by push-out low priority packets at the queue.

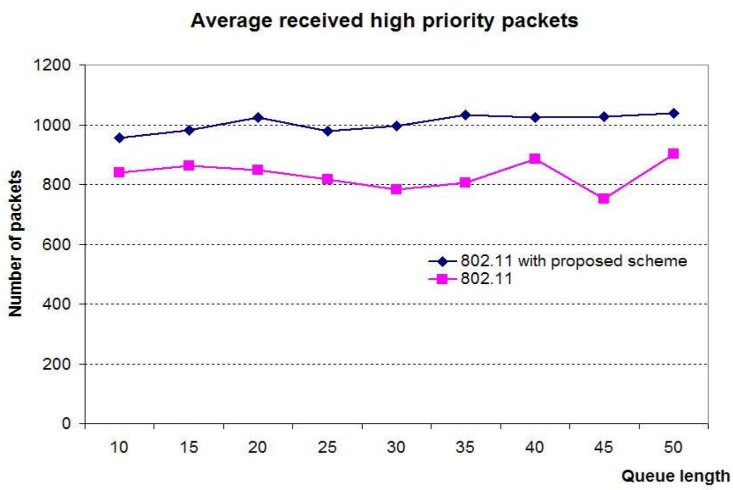

Figure 6. Average number of received high priority packets

As shown in figure 7, which plots average number of lost packets by collision, push-out and load-balancing scheme provide better performance in lost packets by collision than the original IEEE 802.11 MAC protocol. The reason is that; load-balancing scheme provides ability to change the path from congested node to neighbor node in case of collision.

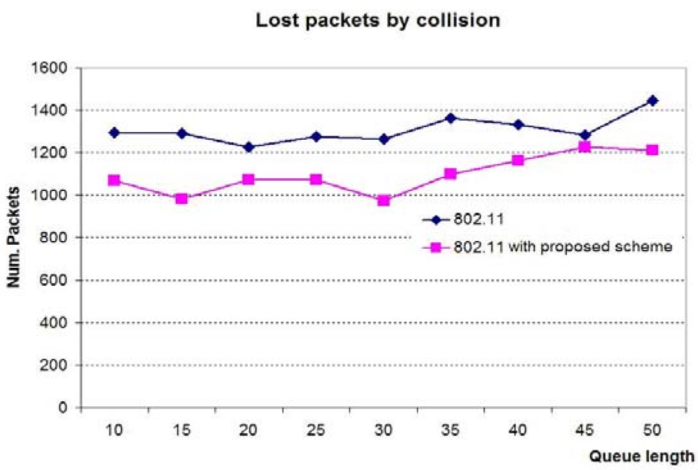

Figure 7. Average number of lost packets by collision

Figure 8 depicts the average number of lost packet by buffer overflow. It shows that the proposed scheme significantly reduces the number of packets lost when the buffer is overflow. The load-balancing is effective in ad hoc network which change topology by arbitrarily movement of mobile nodes.

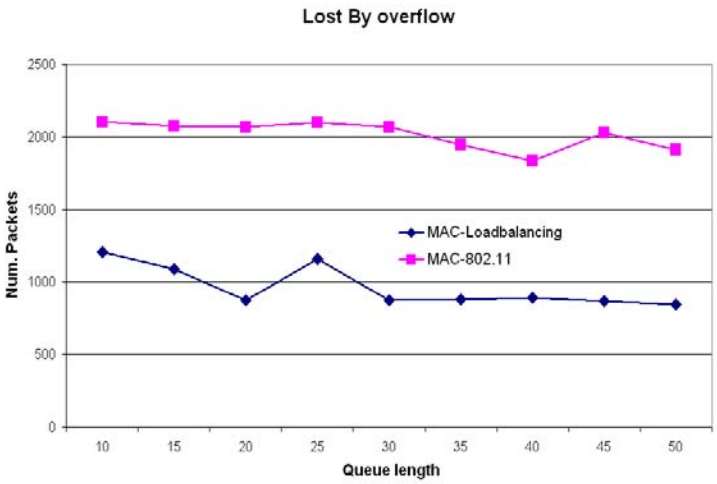

Figure 8. Average number of lost packets by buffer overflow

5.2. Numerical Results of the Random Network Topology

For performance evaluation of the proposed scheme in ad hoc networks, we use a random ad hoc network that consists of 50 mobile nodes in 1.2km × 1.2km area where node's position is generated randomly. Each node moves randomly by using "setdest" command of NS2 simulator. Other simulation parameters are the same as the first model. We execute simulation 10 times to avoid the bias of random number generation where half of flows are high priority class and rests are low priority class. Figure 9 plots average number of received packets with number of flows varies from 10 to 50. We observe that overall throughput increases as the number of flows increases and some of results show that proposed scheme provides better performance than original IEEE 802.11 MAC.

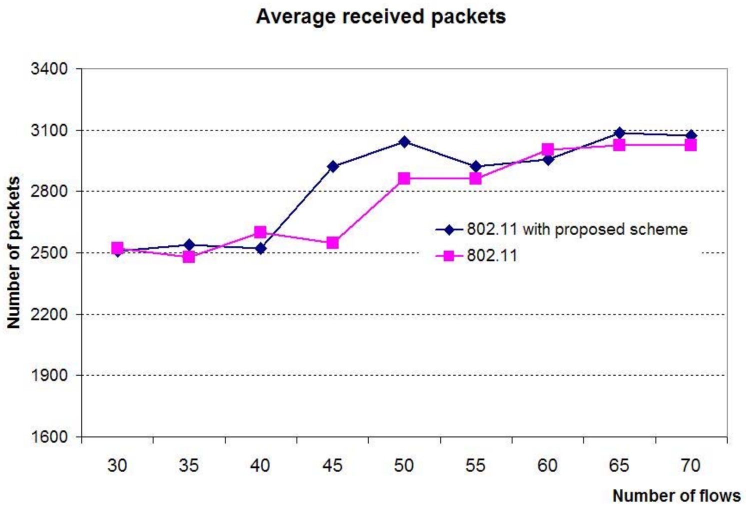

Figure 9. Average number of received packets in the random topology

Figure 10 depicts the average number of lost packets by buffer over-flow. It shows that the load-balancing ability of the proposed scheme is effective in ad hoc network which changes topology by arbitrarily movement of mobile nodes.

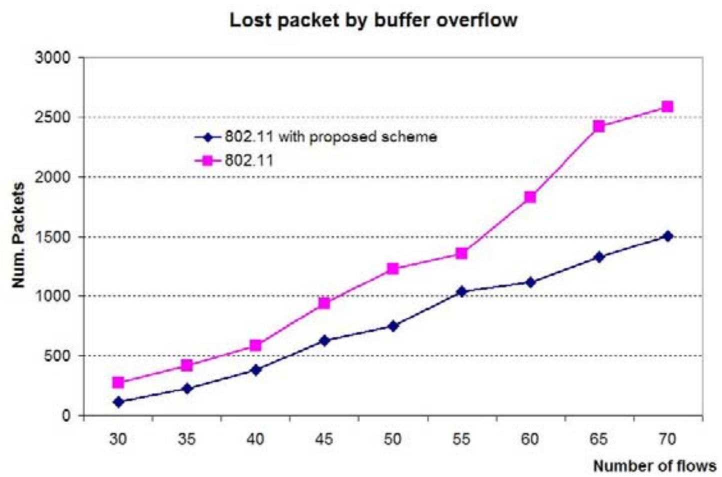

Figure 10. Average number of lost packets by buffer overflow in the random topology

Figure 11 plots the average number of successfully received high priority packets at CBR receivers. In all cases, IEEE 802.11 MAC with proposed scheme provides better throughput than IEEE 802.11 MAC. The proposed scheme is able to increase throughput of high priority class up to 65%.

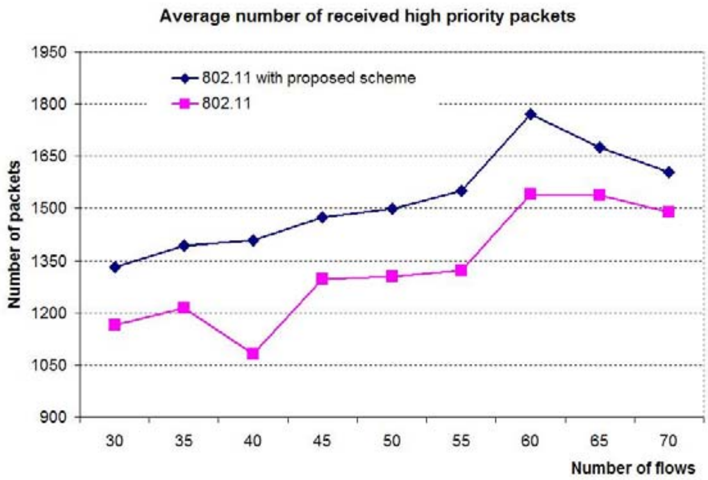

Figure 11. Average number of received high priority packet in the random topology

From figure 9 and 11, we observe that the proposed scheme can provide service differentiation without performance degradation. In general, the results are quite positive in the sense that IEEE 802.11 MAC protocol with the proposed scheme outperformed than original IEEE 802.11 MAC in most cases. Using our technique, load-balancing scheme may improve performance when the traffic load is heavy and should distribute excessive load of a congested node efficiently.

6. Conclusions

In this paper we investigated the performance metrics of buffer management in IEEE 802.11b MAC protocol. The central idea was to present push-out queue management and an efficient load-balancing algorithm in IEEE 802.11 MAC for supporting quality of service in mobile ad hoc networks. Load-balancing ability of our proposed algorithm makes it possible to distribute excessive load of a node to its neighbors and push-out queue management can provide service differentiation in multi-hop ad hoc networks.

Our algorithm takes advantage of distributing and efficiently using network resources (buffer space), reducing network congestion and increasing overall performance (throughput).

For evaluate the validity of the proposed scheme, we compared performance with original IEEE 802.11 MAC by simulation. Simulation results show that load-balancing algorithm distributes excessive load efficiently. Also it shows that push-out and load-balancing algorithm improve throughput of high priority flows and reduce packet loss.

In the following, further investigations should be devoted to assess the algorithm performance in more realistic conditions. It would be also interesting to provide service differentiation with multiple class queuing system with scheduling in layer 2 and compare its performance with original scheme. Scheduler can take in account several parameters as the buffer stat and power consumption.

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